Army Research Laboratory

Wafer Level Antenna Design at 20 GHz

by Theodore K. Anthony

ARL-TR-4425 April 2008

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Adelphi, MD 20783-1197

ARL-TR-4425 **April 2008**

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Theodore K. Anthony
Sensors and Electron Devices Directorate, ARL

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
April 2008

2. REPORT TYPE
Final

3. DATES COVERED (From - To)

4. TITLE AND SUBTITLE
Wafer Level Antenna Design at 20 GHz

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Theodore K. Anthony

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Research Laboratory
ATTN: AMSRD-ARL-SE-SE
2800 Powder Mill Road
Adelphi, MD 20783-1197

8. PERFORMING ORGANIZATION REPORT NUMBER
ARL-TR-4425

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT
This prototype design demonstrates that a compact, efficient, and affordable wafer level antenna is realizable and can be processed along with microelectromechanical system (MEMS) technology on the same material. A coplanar fed proximity coupled patch antenna was ultimately designed to operate at a frequency around 20 GHz (K-Band) for proof-of-concept. Simulation data is compared with the experimental data for validation of model designs.

15. SUBJECT TERMS
Antenna, CPW, HFSS, proximity coupled, wafer.

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Theodore K. Anthony
U	U	U	UU	20	19b. TELEPHONE NUMBER (*Include area code*) (301) 394-1154

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

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Acknowledgment

I would like to thank Daniel Judy, Ronald Polcawich, and Jeff Pulskamp of the U.S. Army Research Laboratory (ARL) for their help in the fabrication process of the wafer level antennas.

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1. Introduction

This prototype design demonstrates that a compact, efficient, and affordable wafer level antenna is realizable and can be processed along with microelectromechanical system (MEMS) technology on the same material. A coupled patch antenna was ultimately designed to operate at a frequency around 20 GHz (K-Band) for proof-of-concept. Simulation data is compared with the experimental data for validation of model designs. The prototype antenna has substrate and ground plane dimensions of 8 by 8 mm, and the high resistivity silicon (Si) wafer is 0.5 mm thick with a dielectric constant of 11.9, a loss tangent of 0.015, and conductivity of 0.025 Siemens/meter (S/m). The Si wafer has gold on both sides that is approximately 0.75 µm thick. A coplanar feed line extends to the edge of the substrate where a SubMiniature Version A (SMA) end launcher is connected to the signal line and ground in the same plane. Since the wafer has a 4 in. diameter, 63 different antennas were produced in addition to the optimized design, to attempt to compensate for the high resistivity Si wafer's effective dielectric constant changing from batch to batch. These are the first antennas on wafer produced by the U.S. Army Research Laboratory (ARL). Figures 1 and 2 show a wafer level antenna prototype of a coplanar fed proximity coupled patch antenna with a dime reference scale and SMA connection.

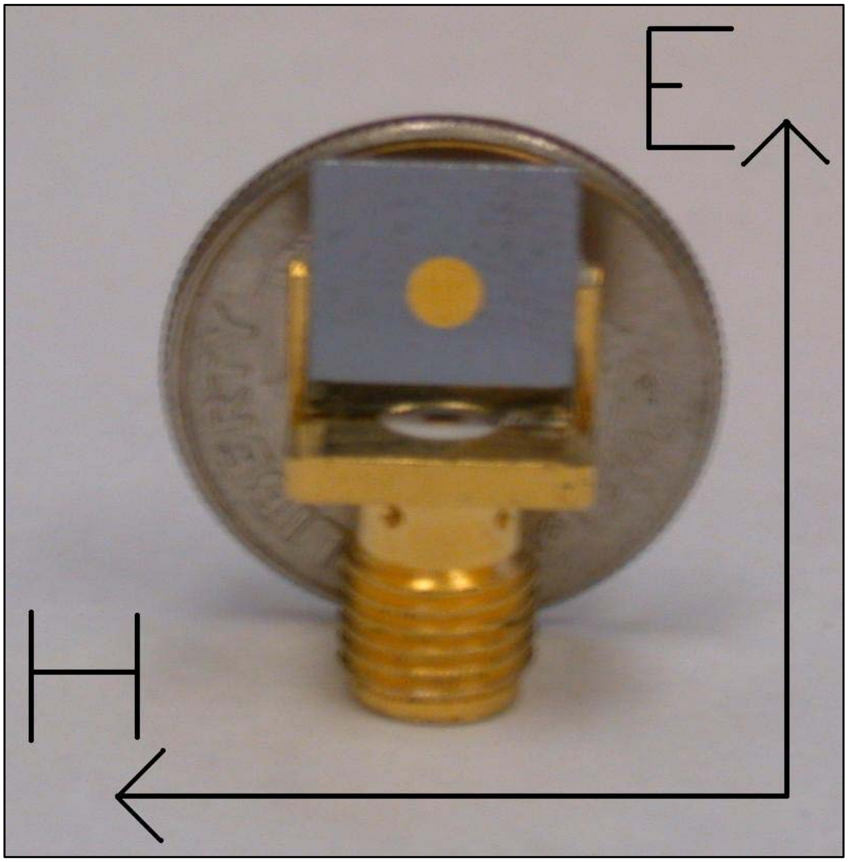

Figure 1. A wafer level antenna prototype, top view, of a coplanar fed proximity coupled patch antenna with dime reference scale and SMA connection.

Figure 2. A wafer level antenna prototype, side view, of a coplanar fed proximity coupled patch antenna with dime reference scale and SMA connection.

The 64 combinations (43) of antennas created on this 4 in. Si wafer vary in the ways presented in table 1. The bolded values are the simulated optimized design dimensions.

Table 1. Combinations of antennas created on 4 in. Si wafer.

mm	Variable dimensions for each parameter			
Length of Stub	0.55	0.60	**0.65**	0.70
Width of CPL	0.90	0.95	**1.00**	1.05
Radius of Antenna	1.05	1.10	**1.15**	1.20

Figures 3 and 4 show AutoCAD layouts of the wafer level antenna prototype.

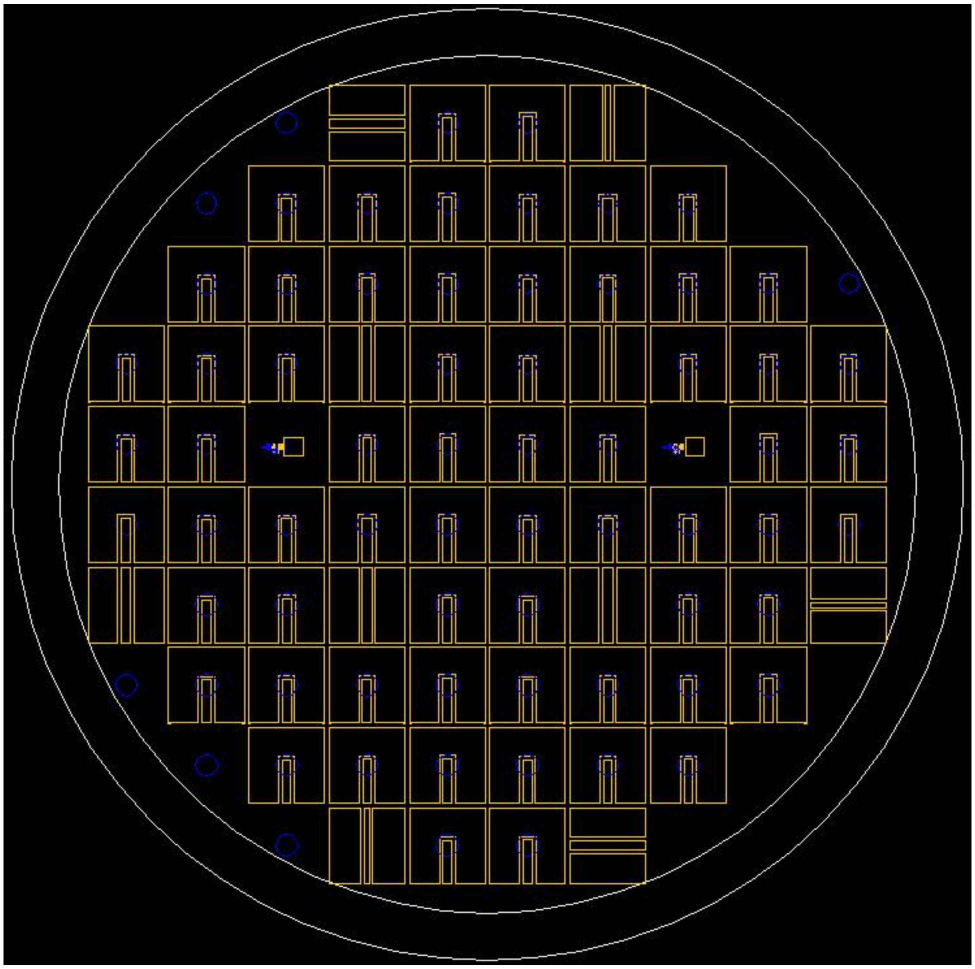

Figure 3. AutoCAD layout of the prototype wafer level antenna to go on 4 in. Si wafer with a label specifying the dimensions of each unique antenna.

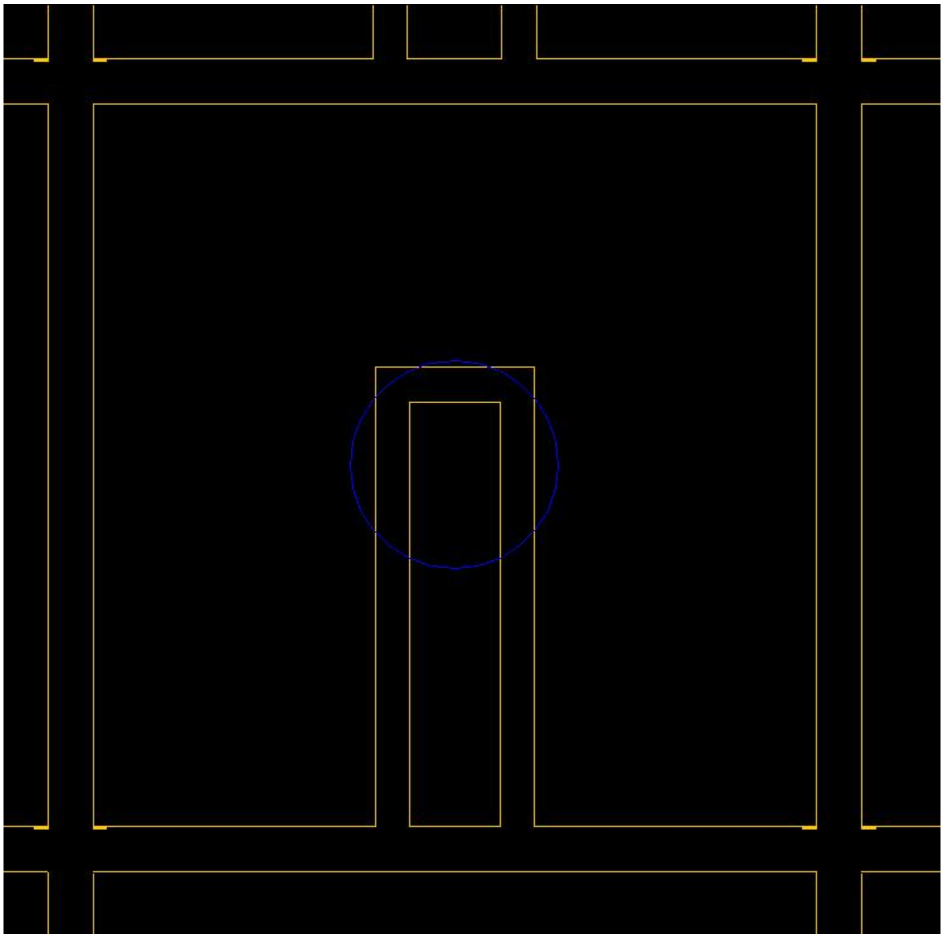

Figure 4. AutoCAD layout of the prototype wafer level antenna simulated and measured with a label specifying its dimensions on the back lower corners.

2. HFSS Simulation

Ansoft's High Frequency Structure Simulator (HFSS), which employs the Finite Element Method (FEM), was developed so that complicated 3-dimensional (3-D) electromagnetic (EM) problems could be solved in an elegant manner with accurate results before prototype construction. Therefore, the correlation between the simulation data and experimental data is maximized to reduce prototyping costs. A full 3-D model of the prototype K-Band patch antenna was designed in HFSS to operate at a frequency around 20 GHz. At that frequency, the free-space wavelength is about 15 mm. This HFSS design included a coaxial cable connection, not the SMA connection seen in figure 1. An actual wafer level antenna with integrated MEMS technology will not have a SMA connection. The SMA connection is needed for measurement purposes. A 3-D HFSS model of a coplanar fed proximity coupled patch antenna with coaxial cable connections are shown in figures 5 and 6.

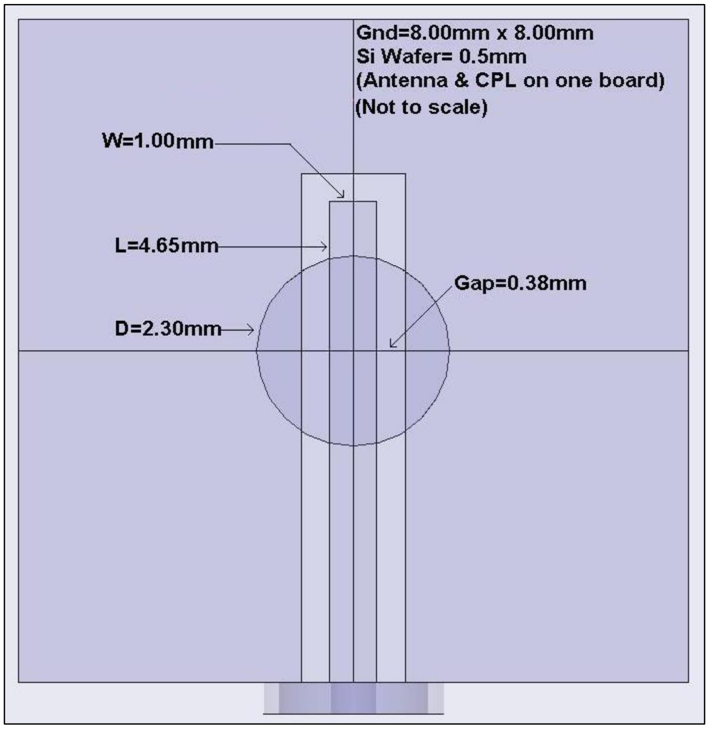

Figure 5. A 3-D HFSS model, top view, of a coplanar fed proximity coupled patch antenna with coaxial cable connection.

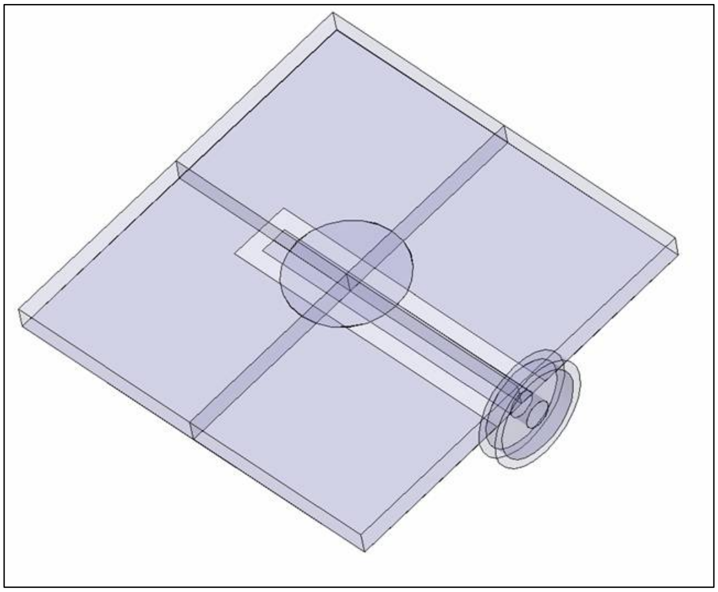

Figure 6. A 3-D HFSS model of a coplanar fed proximity coupled patch antenna with coaxial cable connection.

A port excitation was placed in a 50 ohm coaxial cable feeding the simulated antenna. The convergence study shows that the adaptive meshing was sufficient to do a frequency sweep from 17.5 to 22.5 GHz in 0.01 GHz steps for 501 frequency points. The simulation took 8 min and 48 s to complete. The maximum memory usage was 468 MB of RAM (22,094 tetrahedrals and 122,327 matrix unknowns). Figure 7 shows the HFSS simulated return loss for the modeled wafer level antenna.

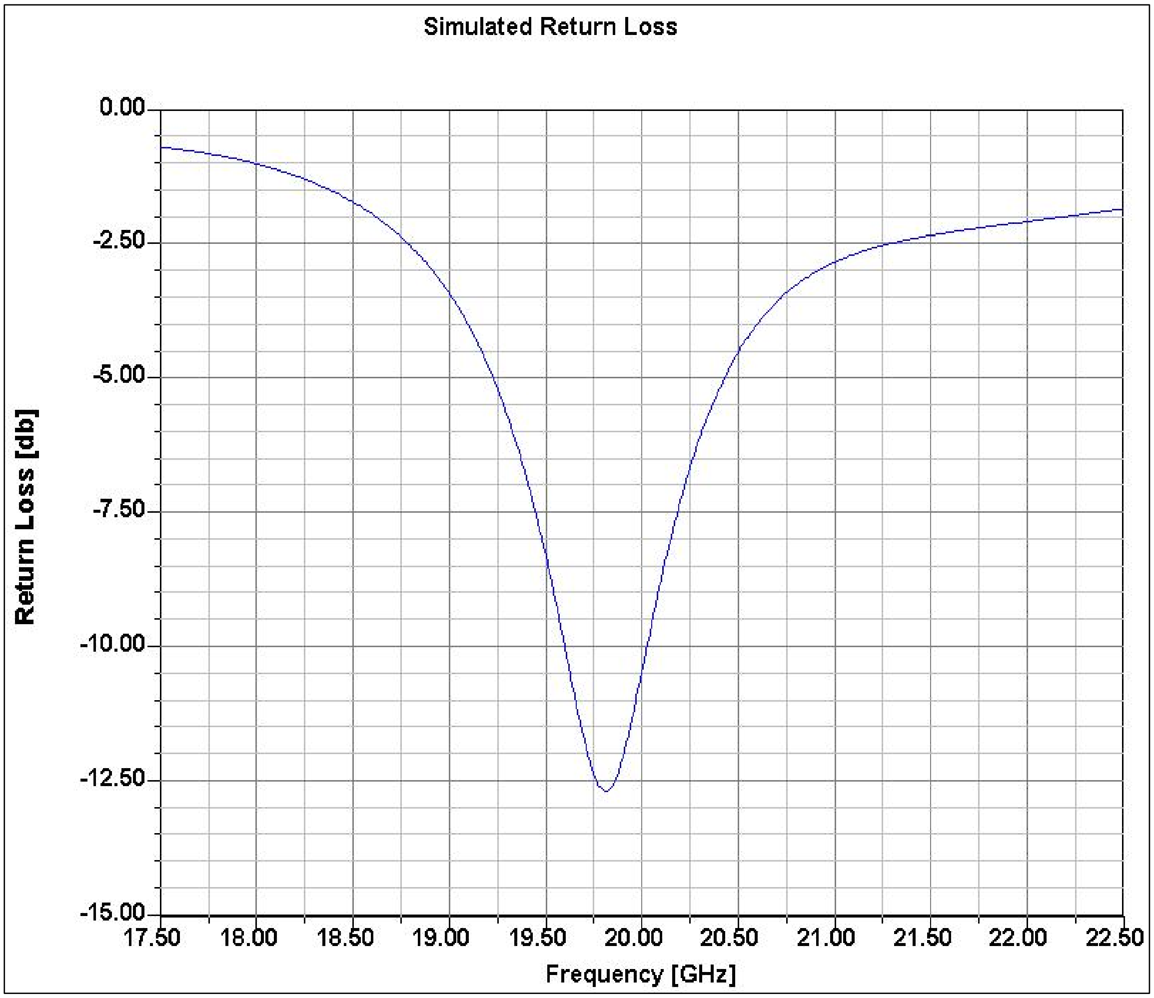

Figure 7. HFSS simulated return loss for modeled wafer level antenna.

A HFSS simulated 3-D radiation pattern for the modeled wafer level antenna is shown in figure 8.

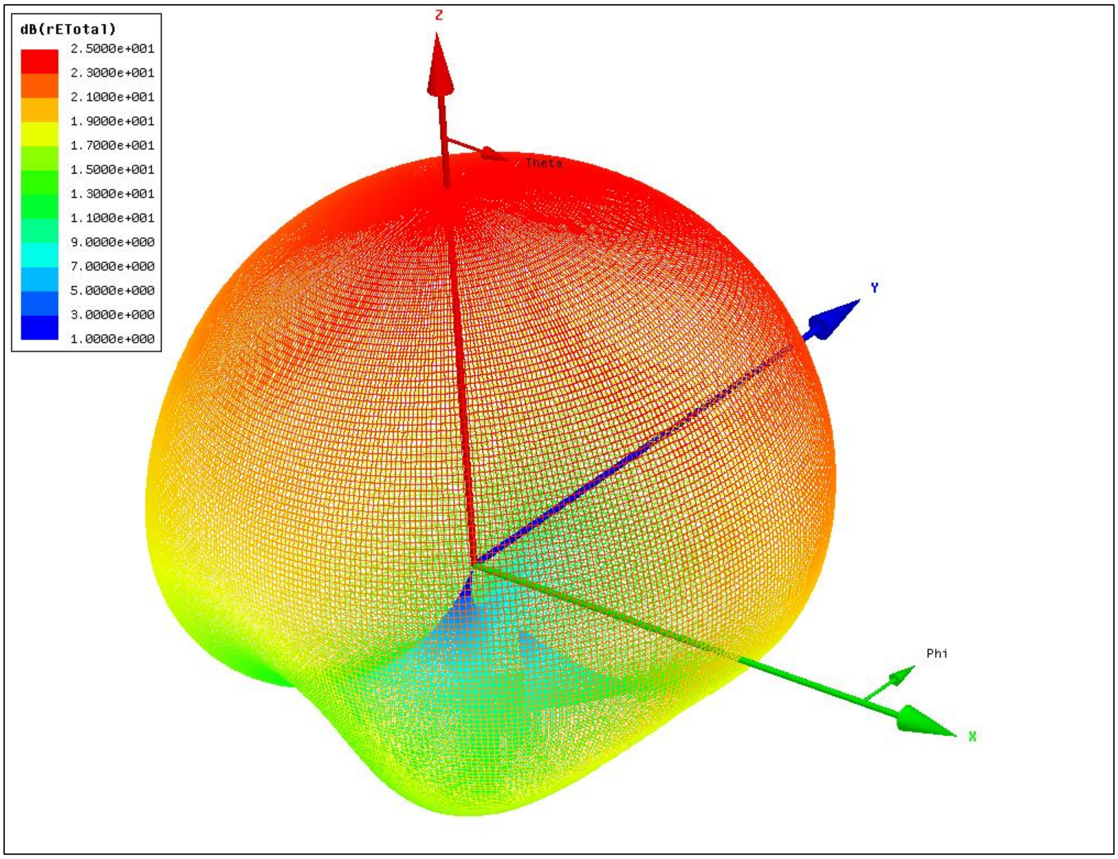

Figure 8. HFSS simulated 3-D radiation pattern for modeled wafer level antenna.

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3. Results

The prototype antennas were fabricated in the Micro-Devices Branch's cleanroom. The gain and radiation patterns were measured in the Millimeter Wave Branch's tapered anechoic chamber. The return loss (S11) was measured on a HP8510 network analyzer. The return loss for the original antenna design shows that the measured resonant frequency (19.80 GHz) is ~0.1% below that of the HFSS simulation results (19.82 GHz). This deviation from the HFSS simulation results can be attributed to the assumed electrical properties of the Si wafer. To account for this frequency shift, the patch antenna's diameter needs to be reduced by ~0.0023 mm (~0.1%) to match the simulated resonant frequency. This was possible to accomplish, but the antenna diameter was only varied by 0.1 mm (~4%) for this first wafer run. The data also

shows that the measured bandwidth is ~0.133 GHz smaller than the HFSS simulation results, which is reasonable. Figure 9 shows a graph of simulated and measured return loss for the wafer level antenna.

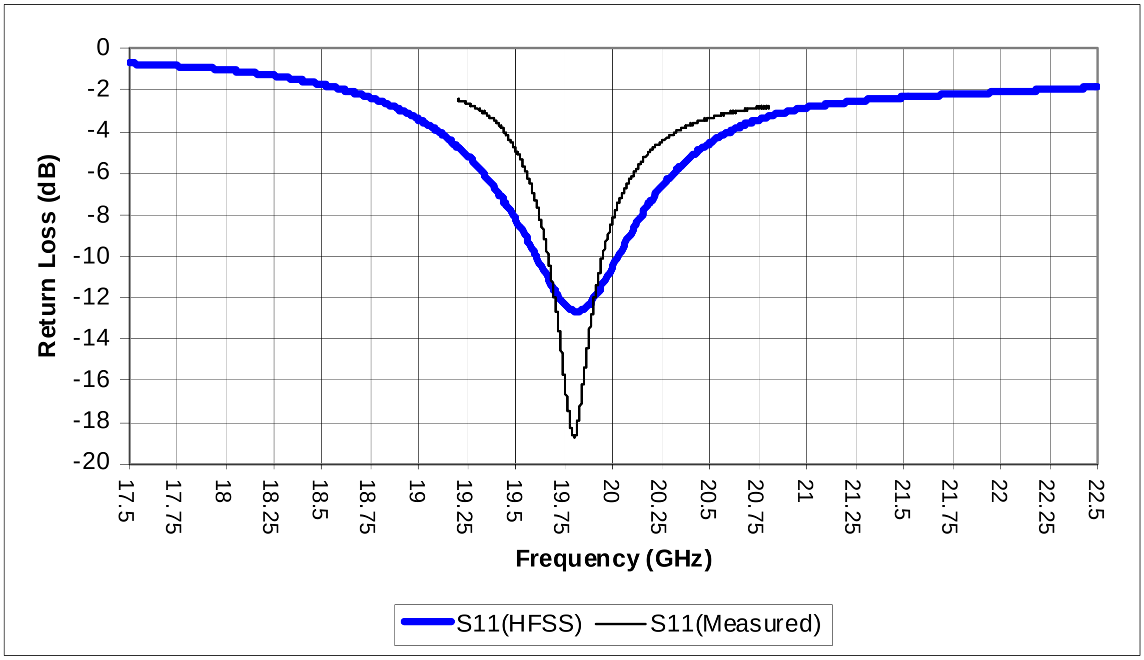

Figure 9. Simulated and measured return loss for the wafer level antenna.

The calculated gain of the wafer level antenna is as follows:

+	Wafer level antenna (power measured dB)	+(-50.3 dB)
–	Standard gain horn-42 (power measured dB)	–(-29.1 dB)
+	Standard gain horn-42 (gain dBi)	+(24.0 dBi)
=	Wafer level antenna (gain dBi)	= 2.8 dBi

The calculated gain (~2.8 dBi) of the antenna is ~1 dB below that of the HFSS simulation results (~3.8 dBi), which is also reasonable.

The simulated and measured E-plane show a front to back ratio around 15 dB. Unfortunately, the radiated E-plane patterns don't match, due to the SMA end launcher interfering with the measured pattern, while a simple coaxial cable was simulated. Figure 10 shows the simulated and measured E-planes for the wafer level antenna, while figure 11 shows the simulated and measured H-planes.

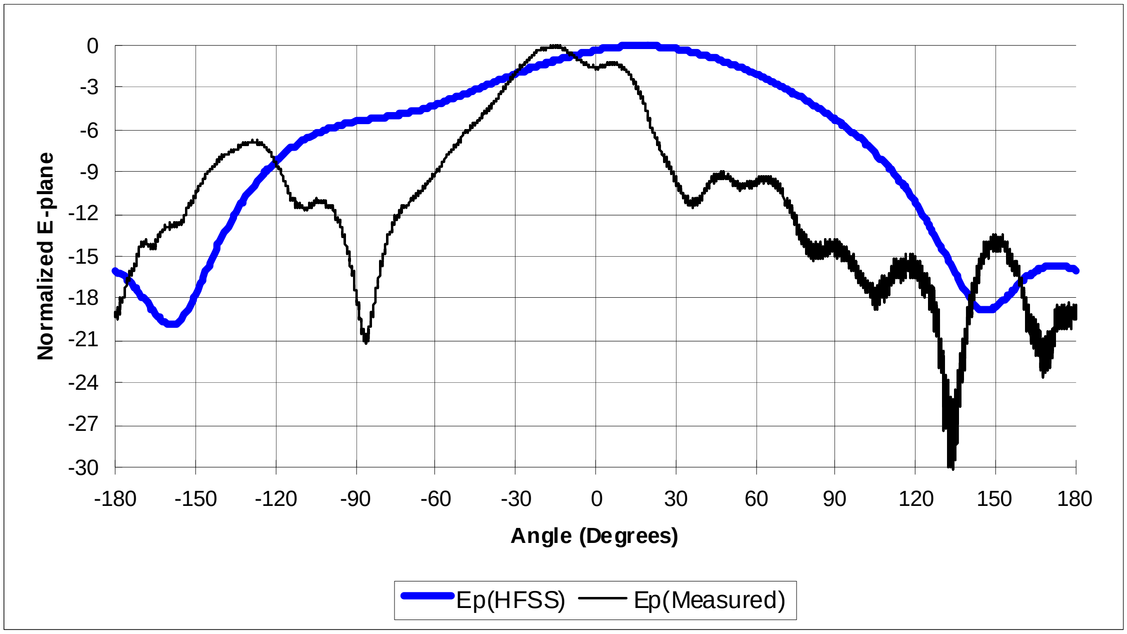

Figure 10. Simulated and measured E-planes for the wafer level antenna.

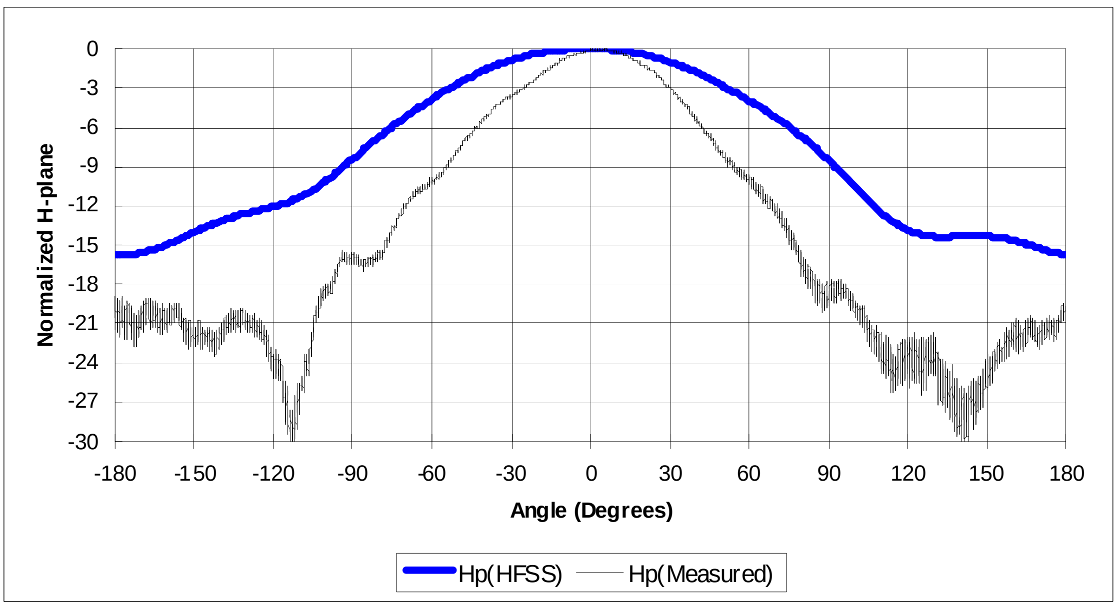

Figure 11. Simulated and measured H-planes for the wafer level antenna.

The simulated and measured H-plane both show a front to back ratio around 15 dB. The measured H-plane (Beamwidth ~55°) turned out even better than the simulated H-plane (Beamwidth ~105°). The radiation patterns do not match, but are of similar shape. This development is under investigation.

4. Conclusion

This prototype design shows that a compact, efficient, and affordable wafer level antenna is realizable and can be processed along with MEMs technology on the same material. This prototype high resistivity Si wafer level antenna at K-Band has demonstrated its proof-of-concept and performance. In addition, HFSS will help evaluate new antenna designs on materials, such as gallium arsenide (GaAs). A full 3-D simulator will continue to be needed to obtain more accurate solutions. Future work will entail simulating the SMA connector effects and comparing the accuracy of the resulting data.

Acronyms

3-D	three-dimensional
ARL	U.S. Army Research Laboratory
EM	electromagnetic
FEM	Finite Element Method
GaAs	gallium arsenide
HFSS	High Frequency Structure Simulator
MEMs	microelectromechanical system
Si	silicon
S/m	Siemens/meter
SMA	SubMiniature Version A

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